# UNITED STATES PATENT APPLICATION

FOR

# METHOD AND APPARATUS FOR CONTROLLING THE SPATIAL TEMPERATURE DISTRIBUTION ACROSS THE SURFACE OF A WORKPIECE SUPPORT

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**Attorney Docket Number: LAM-P0808**

**Client Docket Number: LAM-P0808**

# SPECIFICATION

## TITLE OF INVENTION

**METHOD AND APPARATUS FOR CONTROLLING THE SPATIAL TEMPERATURE DISTRIBUTION ACROSS THE SURFACE OF A WORKPIECE SUPPORT**

## FIELD OF THE INVENTION

The present invention relates to substrate supports. More particularly, the present invention relates to a method and apparatus for achieving uniform temperature distribution within a substrate during processing.

## BACKGROUND OF THE INVENTION

A typical plasma etching apparatus comprises a reactor in which there is a chamber through which reactive gas or gases are flowed. Within the chamber, the gases are ionized into a plasma, typically by radio frequency energy. The highly reactive ions of the plasma gas are able to react with material, such as a polymer mask on a surface of a semiconductor wafer being processed into integrated circuits (IC's). Prior to etching, the wafer is placed in the chamber and held in proper position by a chuck or holder which exposes a top surface of the wafer to the plasma gas. There are several types of chucks (also sometimes called susceptors) known in the art. The chuck provides an isothermal surface and serves as a heat sink for the wafer. In one type, a semiconductor wafer is held in place for etching by mechanical clamping means. In another type of chuck, a semiconductor wafer is held in place by electrostatic force generated by an electric field

between the chuck and wafer. The present invention is applicable to both types of chucks.

During etching in a typical plasma etching operation, the reactive ions of the plasma gas chemically react with portions of material on a face of the semiconductor wafer. Some processes cause some degree of heating of the wafer, but most of the heating is caused by the plasma. The chemical reaction between gas (ions and radicals) and wafer material, on the other hand, is accelerated to some degree by the temperature rise of the wafer. Local wafer temperature and rate of chemical reaction at each microscopic point on the wafer are related to an extent that harmful unevenness in etching of material over a face of the wafer can easily result if the temperature of the wafer across its area varies too much. In most cases it is highly desirable that etching be uniform to a nearly perfect degree since otherwise the IC's being fabricated will have electronic characteristics which deviate more than is desirable. Furthermore, with each new increase in the size of wafer diameter, the problem of insuring uniformity of each batch of IC's from larger and larger wafers becomes more difficult.

The problem of temperature rise of a wafer during reactive ion etching (RIE) is well known, and various attempts in the past to control the temperature of a wafer during etching have been tried. FIG. 1 illustrates one way to control wafer temperature during RIE. A coolant gas (such as helium) is admitted at a single pressure within a single thin space 102 between the bottom of the wafer 104 and the top of the chuck 106 which holds the wafer 104.

There is generally no o-ring or other edge seal at the chuck perimeter except for a smooth sealing land extending from 1 to 5 mm at the outer edge of the chuck 106 in order to reduce coolant leakage. Inevitably, without any elastomer seal there is significant and progressive pressure loss across the sealing land, such that the edge of the wafer 104 is inadequately cooled. The heat impinging near the edge of the wafer 104 must therefore flow significantly radially inward before it can effectively be conducted away to the chuck. The arrows ~~106~~ 108 on top of the wafer 104 illustrate the incoming flux heating the wafer 104. The flow of the heat in the wafer 104 is illustrated with the arrows 110. This explains why the edge zone of the chuck always tends to be hotter than the rest of the surface. FIG. 2 illustrates a typical temperature distribution on the wafer 104. The pressure loss at the peripheral portions of the wafer 104 causes the wafer 104 to be much hotter at the peripheral portions.

One way of dealing with the need for zone cooling is to vary the surface roughness or to cut a relief pattern to effectively change the local contact area. Such a scheme can be used without backside coolant gas at all, in which case the contact area, surface roughness, and clamp force determine the heat transfer. However the local contact area can only be adjusted by re-machining the chuck. Another way of dealing with the need for zone cooling is to use coolant gas whose pressure is varied to increase and fine tune thermal transport. However the pattern is still substantially fixed. By dividing the surface of the chuck into different zones, with or without small sealing lands as dividers, and supplying separate cooling gasses to each zone, a greater degree of independent spatial control may be achieved. The gas supply to each zone may have

different composition or be set to a different pressure, thus varying the thermal conduction. Each zone's operating conditions may be set under recipe control, or even dynamically stabilized during each process step. Such schemes depend on redistributing the incoming heat flux from the plasma and extracting it into different regions. This is relatively effective at high power flux but will only give small temperature differentials at lower power flux. For instance, with about 1W per cm2 of uniform flux and about 3mm sealing land, it is possible to get center to edge thermal gradients that lead to a 10°C to 30°C temperature increase near the wafer periphery. Thermal gradients of this magnitude can be very effective as a process control parameter. However, other processes may run at low power, for instance poly gate processes, may have a flux of only 0.2W per $cm^2$. Unless the average conduction is made extremely low, which is very difficult to control and tends to result in inadequate overall cooling, then there will be only a very small differential of typically less than 5°C.

Accordingly, a need exists for a method and apparatus for controlling the temperature of semiconductor wafers during reactive ion etching and similar processes without requiring significant plasma heat flux.

## BRIEF DESCRIPTION OF THE INVENTION

A chuck for a plasma processor comprises a temperature-controlled base, a thermal insulator, a flat support, and a heater. The thermal insulator has a thermal conductivity of less than about 1W/mK and is disposed on top of the base. The flat support holds a workpiece and is disposed on top of the thermal insulator. A heater is embedded within the flat support. A thermal conductor ensures thermal contact between the flat support and the workpiece. The heater has several heating elements that form several heating zones. The power of each heating element can be controlled independently. A method for controlling the temperature across a workpiece profile having multiple zones provides a base maintained at a constant temperature. The constant temperature is being held below the temperature of the workpiece. The workpiece is held during processing against a top face of a workpiece support in a reactor chamber. A heater disposed below the workpiece heats multiple zones of the workpiece to control the spatial temperature distribution across the surface of the workpiece.

## BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated into and constitute a part of this specification, illustrate one or more embodiments of the present invention and, together with the detailed description, serve to explain the principles and implementations of the invention.

In the drawings:

FIG. 1 is a schematic diagram of a support holding a wafer under process according to a prior art;

FIG. 2 is a schematic diagram illustrating the temperature of a wafer and the pressure of a coolant according to a prior art;

FIG. 3 is a schematic side view illustrating an apparatus for controlling the temperature of a workpiece according to a specific embodiment of the present invention;

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FIG. 4 is a schematic side view illustrating an apparatus for controlling the temperature of a workpiece according to an alternative embodiment of the present invention; and

FIG. 5 is a schematic side view illustrating an apparatus for controlling the temperature of a workpiece according to an alternative embodiment of the present invention.

## DETAILED DESCRIPTION

Embodiments of the present invention are described herein in the context of a method and apparatus for controlling the spatial temperature distribution across the surface of a workpiece support. Those of ordinary skill in the art will realize that the following detailed description of the present invention is illustrative only and is not intended to be in any way limiting. Other embodiments of the present invention will readily suggest themselves to such skilled persons having the benefit of this disclosure. Reference will now be made in detail to implementations of the present invention as illustrated in the accompanying drawings. The same reference indicators will be used throughout the drawings and the following detailed description to refer to the same or like parts.

In the interest of clarity, not all of the routine features of the implementations described herein are shown and described. It will, of course, be appreciated that in the development of any such actual implementation, numerous implementation-specific decisions must be made in order to achieve the developer's specific goals, such as compliance with application- and business-related constraints, and that these specific goals will vary from one implementation to another and from one developer to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking of engineering for those of ordinary skill in the art having the benefit of this disclosure.

The present apparatus seeks to achieve precise thermal control with the capability of the significant thermal differentials, for example over 5°C, but without requiring significant heat flux, for example less than 2W per cm2. FIG. 3 illustrates a schematic side view of an apparatus for controlling the temperature of a workpiece according to a specific embodiment of the present invention. A base 302 or a heat exchanger supports a thermal insulator 304. A support 306, preferably flat, is mounted on top of the thermal insulator 304. A heater 308 is embedded in the support 306. A workpiece 310, such as a wafer, is disposed on top of the support 306. A thermal conductor 312 provides an intimate thermal contact between the support 306 and the workpiece 310. The thermal conductor 312 may be preferably a gas, such as helium. The helium pressure controls the thermal conduction between the workpiece 310 and the support 306.

The base 302 may comprise a metallic material, preferably an aluminum base cold plate, that is maintained at a constant temperature through any standard heat exchange system such as a cooling/heating fluid loop. However, the base 302 must be chilled to a greater extent than in standard operation without the heater 308. That is, the metal base 302 is preferably well below the desired temperature of the workpiece 310.

The thermal insulator 304 acts as a high thermal impedance break between the support 306 and the base 302. The thermal insulator 304 may comprise a thick RTV bonding adhesive made of polymer or plastic. However, the thermal impedance break of the thermal insulator 304 cannot be too excessive otherwise the wafer 310 will be insufficiently cooled. For example, the thermal insulator preferably has a thermal

conductivity of less than about 1W/mK. The thermal insulator 304 in this case both acts as a thermal resistive element and a bond between the support 306 and the base 302. The thickness of the thermal insulator 304 may be preferably about .010".

The support 306 may comprise a ceramic or metallic material. The ceramic may comprise a high temperature non-electrically conductive material, such as for example alumina. The high temperature may include the temperature of a workpiece during a typical plasma etching process, i.e. about 300C. The shape of the support 306 may preferably include a conventional disk commonly used in plasma etching systems. The workpiece 306 may be a conventional electrostatic chuck or may be a ceramic having a mechanical clamp for holding down the wafer 310. The thickness of the support 306 is preferably about 2mm. However any other thickness may be suitable. The support 306 construction may preferably be of a "thin disk bonded to a base" type, otherwise the lateral conduction may be so high that the heater input will be spread laterally resulting in an ineffective zone separation. The thickness of the support 306 may preferably be about 0.040".

The heater 308 may comprise at least one resistive planar element. For example, the heater 308 may be formed with etched foil technology such as a thin film heater. The heater 308 may be embedded in the workpiece support 306 below the clamp electrode plane and be shaped in any desirable pattern, for example, symmetrical or arbitrary. The heater 308 may also have one or more planar heating elements. Each heating element defines a heating zone or region that may be controlled independently. The multi-zone

pattern has one or more planar heating elements acting in opposition to the conduction cooling to the support 306. A sensor (not shown) for each heating zone may measure the temperature on each heating zone and send a signal to a controller (not shown) to monitor and control each individual planar heating element. For example, a sensor such as an infrared emission sensor or thermo-coupled sensor can be mounted either through ports to read directly from the workpiece 310. The sensors can also be mounted within or to the back of the support 306. The heater 308 may be powered by power lines 312 disposed in cavities through the thermal insulator 304 and the base 302.

FIG. 3A illustrates a simplified schematic of the thermal dynamic in the apparatus of FIG. 3. The incoming flux Q1 contributes to the temperature T1 on the surface of the wafer 310. The heater 308 provides additional heat Q2 to the wafer 310. The flux Q2 exiting the system through the workpiece support 306 to the cooled base 302 is approximately equal to both incoming flux Q1 and Q3. Therefore:

$$Q1 + Q3 \approx Q2$$

Using conservation of energy, the sum of the temperature T1 of the wafer 310 and the temperature $\Delta T$ through the thermal insulator 304 is equal to the temperature T1 of the cooled base 302:

$$T1 = T2 + \Delta T$$

It should be noted that $\Delta T$ is defined by the thermal conductivity of the thermal insulator 304. The incoming flux Q3, which is produced by the heater 308, thus controls

$\Delta T$. Therefore, the power of the heater 308 can be adjusted to produce a desired temperature T1 on the surface of the wafer 310 and to compensate for Q1.

Preferably, the temperature of the base 302 is set to produce an exiting flux Q2 of approximately half of the maximum incoming flux of Q3 when there are no incoming flux Q1 and the maximum flux of Q3 is approximately equal to the maximum flux of Q1:

$$Q2 \approx \tfrac{1}{2}\, Q3_{max}$$

$$\text{when } Q1 = 0 \text{ and } Q3_{max} \approx Q1_{max}$$

In this preferred scheme, the range of T1 can vary by +/- $\Delta T$. That is, the temperature of the wafer can be adjusted by controlling the heating power of the heater 308. It should be noted that this scheme requires that the temperature of the base 302, i.e. the coolant temperature, be set 20°C cooler than a conventional apparatus in which the sum of the maximum value of Q1 and the maximum value of Q3 is equal to the maximum value of Q2.

This method of controlling the temperature profile of a wafer on an electrostatic chuck is not only suited to application in a Inductive Coupled Plasma (ICP) processing machine, but also in any other system that may need a low power capability.

FIG. 4 is a schematic side view illustrating an apparatus 400 for controlling the temperature of a workpiece 402 according to an alternative embodiment of the present

invention. A base 404 or a heat exchanger supports a thermal insulator 406. A support 408, preferably flat, is mounted on the thermal insulator 406. A heater 410 is disposed between the support 408 and the thermal insulator 406. The workpiece 402, such as a wafer, is disposed on top of the support 408. A thermal conductor 412 provides an intimate thermal contact between the support 408 and the workpiece 402. The heater 410 may preferably comprise thick film heaters, such as foil heaters, deposited on the back of the support 408. The heaters may be powered by power lines 414.

FIG. 5 is a schematic side view illustrating an apparatus 500 for controlling the temperature of a workpiece 502 according to an alternative embodiment of the present invention. A base 504 or a heat exchanger supports a first interface 506. A thermal insulator 508 is mounted on the first interface 506. A second interface 510 connects the thermal insulator 508 with a support 512. A heater 514 is embedded in the thermal insulator 508 near the top plane of the thermal insulator 508 to create a thermal drop. The workpiece 502, such as a wafer, is disposed on top of the support 512. A thermal conductor 516 provides an intimate thermal contact between the support 512 and the workpiece 502. The heater 514 may preferably comprise plastic film/adhesive heaters embedded in the thermal insulator 508 below the support 512. The heater 514 may be powered by power lines disposed in cavities (not shown) located in the thermal insulator 508, the first interface 506, and the base 504.

The first interface 506 and second interface 510 may comprise a layer of bonding adhesive, such as polymer. The thickness of each interface 506 and 510 may be

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preferably about .003". The thickness of the thermal insulator 514 and the workpiece holder 512 may be preferably about .040" each.

An alternative to using direct electrical heating or coolant at different temperature, may be to circulate the heat or the coolant in a dual or multiple manifold heat sink. This alternative scheme would require a lateral thermal break to separate the heat sink into two or more thermal zones.

FIG. 6A and 6B both illustrate examples of patterns for the heating elements. In FIG. 6A, two concentric spiral heaters 602 and 604 define two distinct zones 606 and 608 respectively. In FIG. 6B, two heaters 610 and 612 define two distinct zones 614 and 616 respectively.

While embodiments and applications of this invention have been shown and described, it would be apparent to those skilled in the art having the benefit of this disclosure that many more modifications than mentioned above are possible without departing from the inventive concepts herein. The invention, therefore, is not to be restricted except in the spirit of the appended claims.